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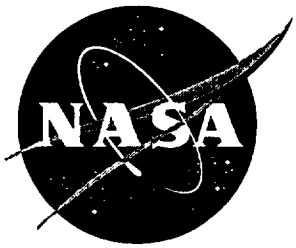

Comparisons of Methods for Predicting Community Annoyance Due to Sonic Booms

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ABSTRACT

Two approaches to the prediction of community response to sonic boom exposure are examined and compared. The first approach is based on the wealth of data concerning community response to common transportation noises coupled with results of a sonic boom/aircraft noise comparison study. The second approach is based on limited field studies of community response to sonic booms. Substantial differences between indoor and outdoor listening conditions are observed. Reasonable agreement is observed between predicted community responses and available measured responses.

INTRODUCTION

Continued interest in future supersonic transport developments has stimulated concern for the associated sonic booms and their effects on communities. Over a period of about 30 years a number of specific flyover tests have been conducted and some additional overflight experience has been accumulated regarding community reactions to sonic booms (refs. 1–10).

A much larger number of related community noise response studies have been performed to assess transportation noises and high-energy impulsive noises. The purposes of this paper are to summarize the subjective reaction data available from sonic boom overflight tests and from other related studies; and to present methods of predicting community responses based on both A-weighted and C-weighted metrics for comparison.

ANNOYANCE CRITERIA

The opportunity is taken to evaluate two different approaches to the assessment of annoyance in communities due to sonic booms from overflying supersonic aircraft. The first approach is to make use of the very large data base of community response data collected by Schultz (ref. 11) relative to noises from subsonic aircraft, road traffic, and railroads. A subsequent effort (ref. 12) updates the original Schultz findings with data from additional social surveys conducted since the publication of ref. 11. Although the total number of data points more than tripled for this new study, it was concluded that the original relationship formulated by Schultz provides a reasonable fit to all of the available transportation noise data. These results are summarized in Figure 1, which shows the percentage of the population highly annoyed by subsonic transportation noise as a function of noise level. The primary descriptor is day-night average A-weighted sound level (L_{dn}).

The second approach is supported by documentation in refs. 13 and 14, and can be described with the aid of Figure 2. Figure 2 is based on the tabulated values from Appendix B of Ref. 14. The percentage of the population highly annoyed is shown as a function of L_{Cdn}, which is defined as day-night average C-weighted sound level. C-weighting is proposed as a more appropriate metric for assessing high-energy sounds such as sonic booms, quarry blasting, and artillery sounds, which can excite noticeable vibrations in buildings and other structures and can induce secondary auditory effects such as house rattling. These vibrations-related phenomena are widely recognized as being significant in the responses of sonic boom listeners who are located indoors.

With regard to the two assessment approaches described above, the L_{dn} metric should be appropriate for out-of-doors listening, whereas the L_{Cdn} should be more appropriate for in-doors listening. Human response data from refs. 1 and 2 are in a form that permits the testing of the above hypotheses.

AVAILABLE SONIC BOOM DATA BASES

The most comprehensive study of subjective reaction to individual sonic booms was conducted during the flight tests at Edwards Air Force Base, as reported in refs. 1 and 2. Additional significant field data are available from the Oklahoma City flight tests (refs. 3 and 4), the St. Louis flight tests (refs. 7 and 8), the Edwards community survey (refs. 1 and 2), the British exercise Westminster (refs. 5 and 6), and the French community surveys (refs. 9 and 10).

The sonic boom test results that are used as a basis for the development of the proposed community response prediction method were obtained in a series of overflight studies conducted at Edwards AFB during the period of June 1966-January 1967 (refs. 1 and 2). The general test layout is shown schematically in Figure 3. The human subjects were arranged into indoor and outdoor juries in a test area remote from normal military operations. Supersonic aircraft at relatively high altitudes and subsonic aircraft at relatively low altitudes were vectored over the test area in a planned sequence and on a tight schedule. Measurements of aircraft noise, sonic booms, and associated building vibration responses (ref. 15) were made for all test flights for correlation with the subjective results.

A total of 300 human test subjects were used in indoor and outdoor listening situations. The indoor listeners were deployed in houses specially constructed to be

representative of typical midwestern U.S.A. houses from the 1970s, and were in the near vicinity of the outdoor listeners. About 100 of the subjects were from the Edwards AFB area, where they had previous exposure over an average period of 2-1/2 years to about four to eight sonic booms per day. The other test subjects were from communities that were not routinely exposed to sonic booms. Test noises were presented in pairs consisting of two booms, two flyover noises, or one of each.

The subjects judged the relative acceptability of the sounds from each pair of vectored flights and also rated the first of each pair of sounds on a numerical scale from very acceptable to unacceptable. As an example, the previously exposed persons judged the boom from either a F-104, B-58, or XB-70 of about 1.7 psf to be about as acceptable as the flyover noise from a subsonic jet aircraft at a maximum level of 109 PNdB when exposed outdoors. These results are comparable to those from Project Westminster (refs. 6 and 16), in which 1.7-psf booms from a Lightning aircraft were judged to be equal to 110 PNdB when judged indoors and 105 PNdB when judged outdoors.

The naive subjects, under the Edwards test conditions, judged comparable noise levels to be higher by 8–10 PNdB indoors and 5-8 PNdB outdoors. Thus, to these naive subjects, the booms were markedly less acceptable than they were to the more experienced subjects.

All sonic boom data presented in the following figures are from the experienced subjects. They were chosen in order to represent the long-term, steady-state conditions, which are also implicit in the community response data of refs. 11 and 14.

They obviously do not properly represent the initial reactions to sonic booms by naive subjects with little previous exposure experience.

In the paired comparison tests (refs. 1 and 2), aircraft sounds were presented in pairs with approximately 1 to 2 minutes between the members of each pair and a minimum interval between pairs of 4 to 5 minutes. Each experimental condition was repeated four times, twice with sound A of the pair given first and twice with sound B of the pair given first. The subjects' task was to indicate on an answer sheet which sound of each pair would be the more acceptable if it were to be heard in or near their homes.

Figure 4 shows some sample results from one of the boom evaluation tests. Note that three data points are included for both the outdoor and indoor listening situations. They represent an average response from the listeners as to whether the particular sonic boom presented (Δp_o = 2.8 psf) was preferable to the various comparison aircraft flyover noises. The 50-percent point on each diagram is assumed to be at the airplane noise level which is equivalent in acceptability to the example sonic boom having an overpressure of 2.8 psf. Other similar paired comparisons at different overpressure levels were made, from which the equivalence data of Figure 5 were obtained.

The results of Figure 5 suggest that there is a linear relationship between the maximum recorded flyover noise levels and the log of the measured sonic boom overpressures for equal acceptability for either the indoor or the outdoor listening situation. This linear relationship is fortuitous and facilitates our desired extrapolation to lower and higher sonic boom overpressures in Figures 6 and 9. It can be seen that the slopes are different for the indoor and outdoor situations. A doubling

of the sonic boom overpressure is associated with a 9.5-dB increase in perceived noise levels for the indoor subjects. On the other hand, the corresponding increase for the outdoor subjects is about 14 dB. This higher slope for outdoor listening conditions may possibly be attributed to the shorter rise times generally ascribed to the higher Δp_o values. Shorter rise time signatures have more high-frequency content and, hence, are usually observed as being louder (ref. 17). Outdoor subjects would be affected directly, whereas the building structures would attenuate the high frequencies for indoor subjects. On the other hand, indoor subjects are exposed to induced vibrations and secondary auditory effects.

A general result of the above tests is that the equivalent perceived noise levels were always higher for the indoor subjects than for the outdoor subjects for any given sonic boom overpressure (measured outside) within the test range.

EXAMPLE ANNOYANCE PREDICTIONS

Methods are presented for predicting community responses to sonic booms based on both A-weighted and C-weighted metrics. The results are compared with available data.

Outdoor Subjects

The "outdoor subjects" line of Figure 5 is carried over to Figure 6 as an aid in displaying the equivalent noise exposure level for different sonic boom exposure scenarios, and is identified with a one-boom-per-day exposure rate. Data for one-boom-per-day are extrapolated to other boom repetition rates by assuming a 3-PNdB increase for each doubling of the boom repetition rate. The curves of

Figure 6 for exposure rates from 1 to 64 booms per day are used later in this paper as a basis for prediction of community response.

Also shown on Figure 6, on the right hand side, is an equivalent day-night average sound level (L_{dn}) scale for aircraft flyover noises. The relationship between the maximum value of perceived noise level and L_{dn} is estimated from the appropriate information on pages 136 and 137 of ref. 18. For single events occurring during daylight hours, the L_{dn} value of flyover noise is noted to be 47 dB lower than the corresponding maximum value of perceived noise level. Based on the jury tests equating perceived noise levels and sonic boom overpressures, their equivalence with the metric L_{dn}, as indicated in Figure 6, is assumed to also be valid. This is a useful result, because it provides the mechanism for producing the curves of Figure 7 from the data of Figures 1 and 6. For the purposes of this paper in the development of the sonic boom annoyance prediction method proposed for out-of-doors listeners, the Schultz curve is selected. It is recognized as the best currently available estimate of community annoyance due to subsonic aircraft and surface transportation noises. Furthermore, it is based on a very large data sample.

Predicted annoyance due to sonic booms is shown in Figure 7. Percentage of the population highly annoyed is plotted as a function of sonic boom overpressure for various boom repetition rates. The individual curves are constructed from the information included in Figures 1 and 6, and they will be referred to as Kryter-Schultz curves. For a given sonic boom level and repetition rate, the equivalent L_{dn} value was obtained from Figure 6. This value, in turn, was used to derive the percentage highly annoyed from Figure 1.

The resulting prediction curves of Figure 7 indicate the expected community response in terms of percentage highly annoyed for a range of sonic boom overpressures and repetition rates. As an example, 10 percent of the population is predicted to be highly annoyed by exposure to 64 booms per day at an overpressure of 0.83 psf or to one boom per day at an overpressure of 2.0 psf.

An obvious question is: How realistic are the predictions of Figure 7? In order to answer that question, the data of Figure 8 are presented. Predictions for 16 booms per day, based on Kryter-Schultz (Fig. 7), are compared in Figure 8 with independently obtained results of the Edwards jury tests (refs. 1 and 2). In these tests, the subjects were asked to give an absolute rating to the first of each pair of airplane noises or sonic booms heard during the tests. They were asked to note whether or not that particular noise would be acceptable if heard at home 10–15 times each day. The results of these jury tests are indicated by the square data points in Figure 8. Each data point indicates the percentage of the jury who said that outside booms of a particular overpressure were unacceptable if experienced 10–15 times each day.

Also included is a curve of short dashes, which has been faired through the Oklahoma City interview results, as tabulated in Table 2 of ref. 18, and which represents the serious annoyance of persons exposed to eight booms per day. Assuming that the terms "serious annoyance," "highly annoyed," and "unacceptable" are roughly equivalent, the three sets of data can be compared and are seen to be generally consistent.

Indoor Subjects

Similar human reaction results are available for subjects exposed to sonic booms while inside of house structures. Two sets of data are presented.

Kryter-Schultz. The first set of data is that from the indoor subjects of Figure 5. These data were obtained simultaneously with those of the outdoor subjects that have been presented in Figures 6, 7, and 8. The indoor curve of Figure 5 is carried over to Figure 9, is extrapolated to both higher and lower values, and is labeled "1 boom per day." The higher order exposure curves of Figure 9 were constructed in the same manner as those in Figure 6 and are used in connection with Figure 1 to produce the prediction curves of Figure 10. Note that a comparison of Figures 6 and 10 indicates a consistently higher percentage of highly annoyed persons for the indoor listeners compared to the outdoor listeners, for the same nominal sonic boom exposures.

ANSI. The National Research Council CHABA Committee (ref. 13) and subsequent ANSI standard (ref. 14) proposed an alternate method for assessment of high-energy impulsive sounds with respect to residential communities. This method, based on "C"-weighted sound level, is illustrated in Figure 2. The Edwards data did not contain any "C"-weighted metrics. These quantities have, however, been retroactively estimated for the Edwards tests based on results of recent overflight measurements for aircraft operations similar to those of the Edwards study (ref. 19). These latter results, which are shown not to be sensitive to different sizes and types of aircraft, suggest that day-night average C-weighted sound levels are empirically related to peak sound pressure levels. Conversions are based on the following analysis:

$L_{Cdn} = L_{ce} + 10LogN - 49.4$, dB

where L_{ce} is C-weighted sound exposure level in dB and N is the number of events per day.

Thus, when N = 1 daylight flight,

$$L_{Cdn} = L_{ce} - 49.4 \text{ dB}$$

$$L_{ce} = L_{pk} - C, \text{ dB}$$

where L_{pk} is peak sound pressure level and C has been evaluated empirically to be 26.6 dB in ref. 19.

Shown graphically in Figure 11 is the relationship between L_{Cdn} and L_{pk}, as well as the equal energy concept. Note that no subjective response data are included in Figure 11. The data of Figures 2 and 11 are used to produce the set of ANSI curves of Figure 12 for predicting the response of indoor listeners. Predictions of "highly annoyed" are given for a range of sonic boom overpressures and for different repetition rates. As an example, a 10-percent highly annoyed response would be predicted for 64 booms per day at an overpressure of 0.29 psf, or for 1 boom per day at an overpressure of 2.2 psf.

The indoor prediction results of Figure 12 are compared with other similar data sets in Figure 13. As in the discussion of Figure 8, the terms "highly annoyed," "unacceptable," and "seriously annoyed" are assumed to be roughly equivalent. The 16 booms per day ANSI and Kryter-Schultz curves are shown along with the

indoor Edwards jury results for 10–15 booms per day and the Oklahoma City data for 8 booms per day for comparison. There is more scatter than for the outdoor data of Figure 8. The predictions are, however, generally consistent with the Oklahoma City data and the Edwards jury data.

In comparing the indoor results of Figure 13 with the outdoor results of Figure 8, it can be seen that for the same outdoor exposure, the indoor subjects are relatively more annoyed. It should be noted that the Oklahoma City data line is the same in Figures 8 and 13, and is defined by a mixture of indoor and outdoor observations. Thus, it would be expected to fall relatively high on Figure 8 and relatively low on Figure 12.

COMPARISONS WITH OTHER OVERFLIGHT DATA

The general consistency of the data sets of Figures 8 and 13 suggests that useful comparisons may also be made with other data sets and observations from a number of independent field studies involving supersonic aircraft flyovers, as shown in Figures 14 and 15. Available data are grouped together for comparison with predicted curves of 13 percent and 25 percent highly annoyed, respectively, for both inside and outside observers. In each case, the figure legends give the sources and associated community responses.

The triangle data point in Figure 13 and the hatched area in Figure 14 come from a series of French community surveys in regions where Concorde and military operations were conducted (refs. 9 and 10). Nearly 4,000 interviews of people 20 years of age or older were accomplished by the Institute Francais d'Opinion Publique in November 1970.

Residents of Edwards AFB were asked in mail questionnaires to rate the noise conditions present when about 10 booms per day were experienced during the subjective tests and also for the preceding period when the boom exposure rate was estimated to be four to eight booms per day. These results, from refs. 1 and 2, are represented by the hatched area on Figure 14 and the circle data point on Figure 15. Likewise, the cross-hatched areas in both figures represent the absolute judgment results of the Edwards jury tests involving 120 respondents located indoors and outdoors. These latter results are taken from the data shown in Figures 8 and 13, and are points on a faired curve through those data (refs. 1 and 2).

The Oklahoma City, Oklahoma, area was repeatedly exposed to sonic booms during simulated supersonic transport overflights conducted at a rate of eight per day for a 6-month period (refs. 3 and 4). Data were collected along the ground track and at various lateral distances from it. Overpressure values varied from 0.65 psf to 1.60 psf. Nearly 3,000 local residents were personally interviewed three times during the 6-month period to determine the nature and extent of their reactions to the sonic booms. Interpretations of the results of the above tests in terms of percentages of the population who were highly annoyed are provided in ref. 18 and are presented in Figures 14 and 15 as the square data points. Other interpretations of the Oklahoma City data are provided in ref. 20 and are plotted as the diamond data points.

The speckled areas in both figures represent results of community reaction flight experiments over the city of St. Louis, Missouri. A series of special military flights in a 2-month period (refs. 7 and 8) was conducted to supplement routine military supersonic traffic over the area. The frequency of boom exposures in the test area varied over a 5-month period from a low of four per month to a high of six per day.

One set of interviews was conducted for 1,145 persons, and 1,011 of them were re-interviewed about a month later to assess their reactions to both exposures.

The various data sets shown in Figures 14 and 15 all relate to actual supersonic flyovers of people and communities. The methodology varied from one study to another and the terminology used to describe the results also varied. As is indicated in the legends of Figures 14 and 15, the terms "serious annoyance," "highly annoyed," "unacceptable," and "great annoyance" are assumed to be comparable for purposes of the figures. The term "annoyed" from the French tests is believed, however, to represent a less negative reaction than do the other terms noted above.

Based on the above assumptions, the available field results seem to be in reasonable agreement with the Kryter-Schultz and the ANSI predictions for 13 percent highly annoyed in Figure 14. A notable exception is the French data point, which falls relatively low on the plot, probably for the reason stated above. Reasonable agreement is also seen in Figure 15, although the French data and the St. Louis data fall relatively low. They are, however, roughly consistent with the other data sets.

Note that the ANSI and Kryter-Schultz prediction lines have markedly different slopes in Figures 14 and 15. The Kryter-Schultz predictions give the more conservative results at high values of sonic boom overpressure for which the startle and loudness effects may be the most significant. The greater slopes of the Kryter-Schultz lines arise from the greater-than-unity slopes of both the inside and outside response lines of Figure 5. On the other hand, the ANSI predictions are more conservative at the lower sonic boom overpressures, which are likely to be in the

operating range of some future supersonic aircraft. The ANSI line is consistent with the equal energy hypothesis expressed in Δp or L_{Cdn}, i.e. 3 dB per doubling of number of booms per day.

The data of Figures 14 and 15 are compared with the ANSI curve in a different format in Figure 16. All flyover data are converted to L_{Cdn} units and appropriate adjustments are made for numbers of booms per day. Generally good agreement is seen in Figure 16 with the flyover data, which tends to scatter about the ANSI curve.

COMPARISONS WITH OTHER PREDICTIONS

Further comparisons of available estimates of community reaction to sonic booms are presented in Figure 17 from references 21 and 22. Percentage acceptance on a probability scale is shown for a range of sonic boom overpressure levels. The straight lines marked "Leyman" (ref. 21) and "Wyle" (ref. 22) are two interpretations of the available data with particular emphasis on the Edwards AFB results (refs. 1 and 2). Based on the assumption that "percentage acceptance" is equivalent to the inverse of "highly annoyed" in Figures 8 and 12, the lines marked Kryter-Schultz outdoors, Kryter-Schultz indoors, and ANSI are included for comparison.

The Kryter-Schultz outdoors line, which represents a 16-boom-per-day exposure rate, is nearly coincident with the Wyle line. The Ansi and Kryter-Schultz indoors lines are in close agreement. They have markedly different slopes, and for sonic boom exposure levels less than 2 psf, predict a lower rate of acceptance than do the Wyle and Kryter-Schultz outdoors lines.

CONCLUDING REMARKS

Methodology for predicting the percentage of the population that would be highly annoyed by sonic booms has been formulated. It encompasses indoor-outdoor responses for steady-state flight conditions and includes the effects of sonic boom overpressures and repetition rates. It is based on the results of Kryter's sonic boom flyover tests for experienced subjects, the synthesis of available community noise data by Schultz for aircraft, highway, and railway noise sources, and the Ansi approach to the assessment of high-energy impulsive sounds, which may induce house vibrations. Reasonable agreement is shown between the predicted percentages of highly annoyed persons and the interpreted results from several individual community surveys involving supersonic overflights.

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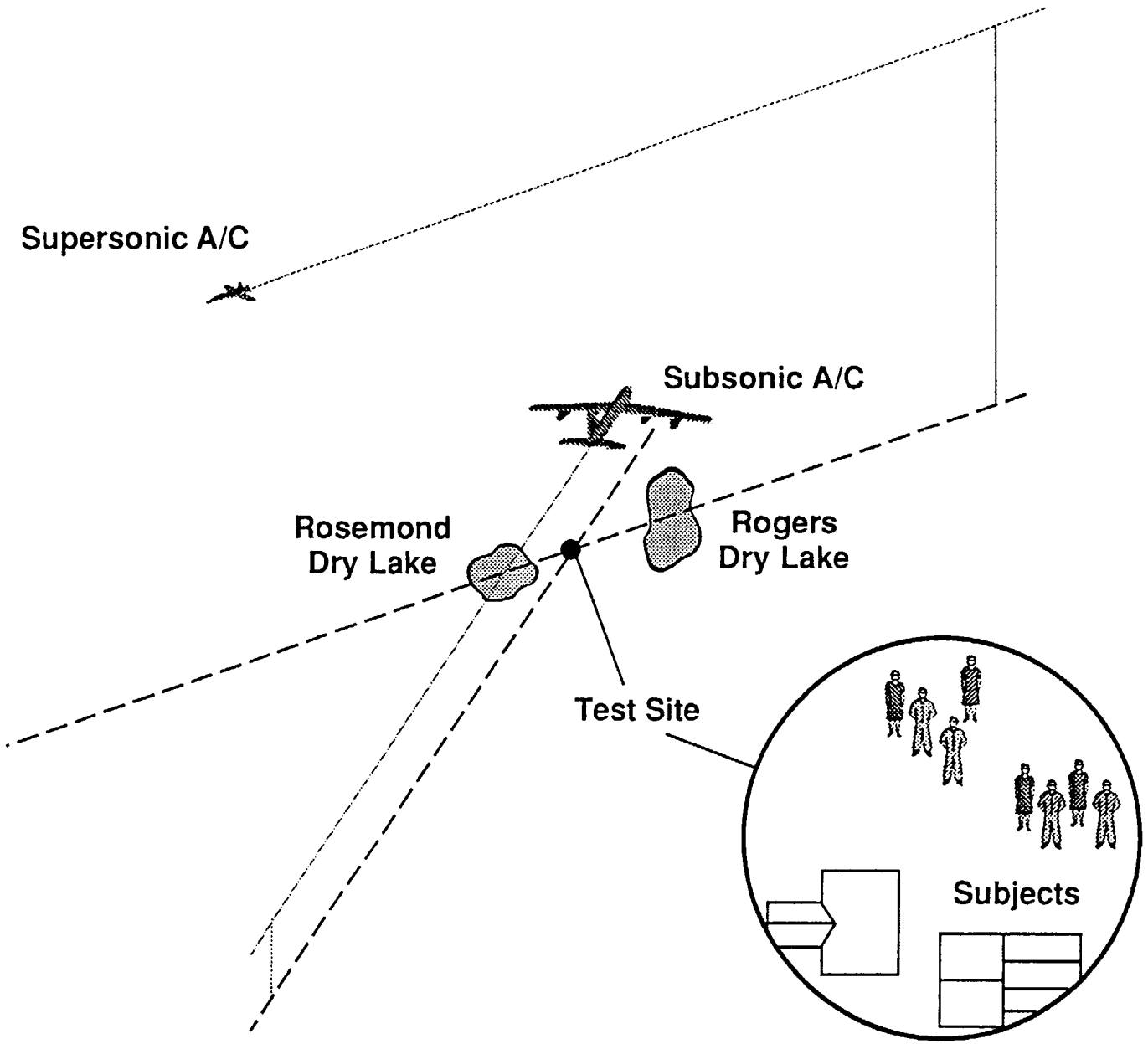

Figure 3. Field test setup for the Edwards AFB sonic boom exposure studies (refs. 1 and 2).

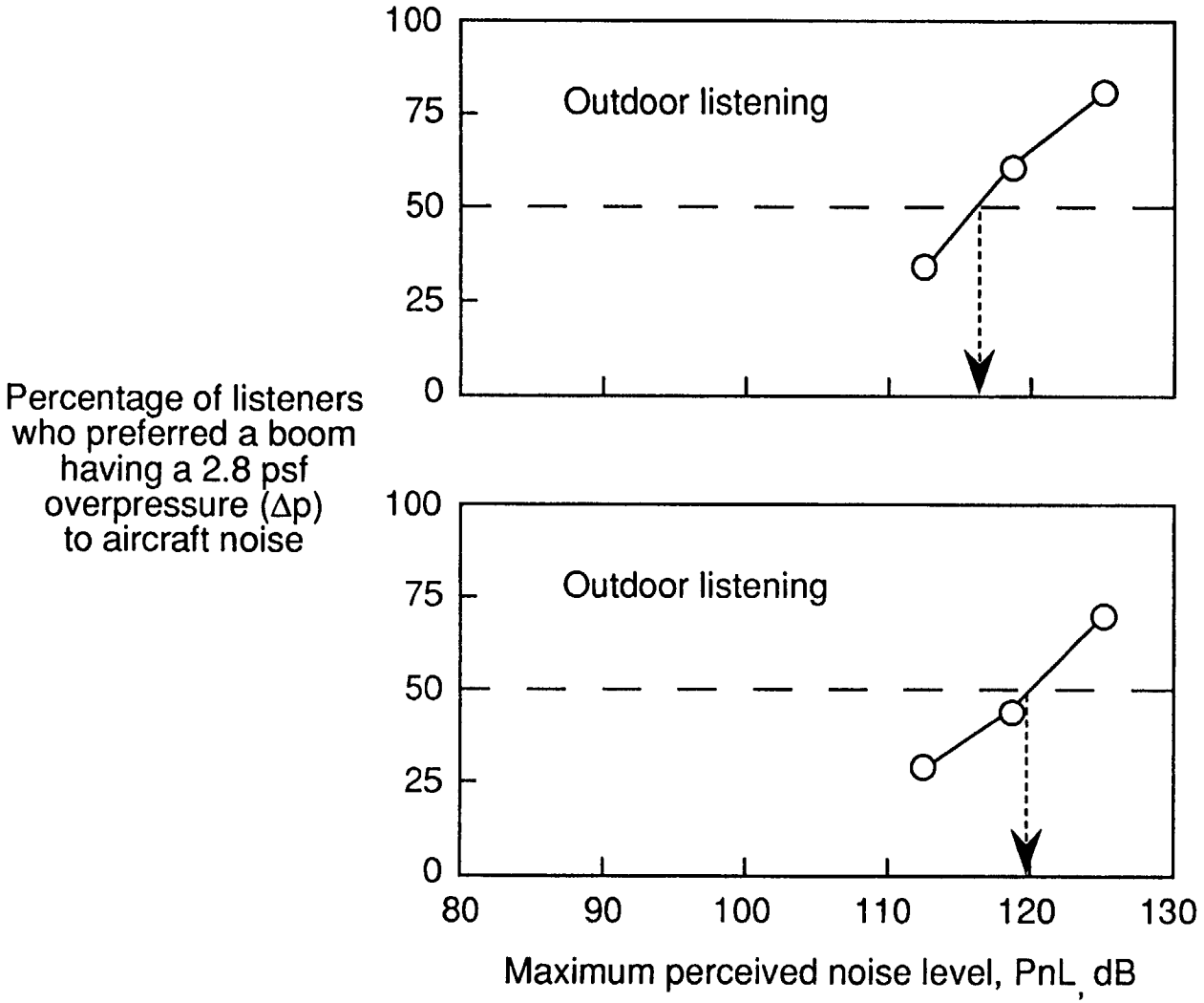

Figure 4: Example results from the Edwards AF paired comparison listening tests (refs. 1 and 2).

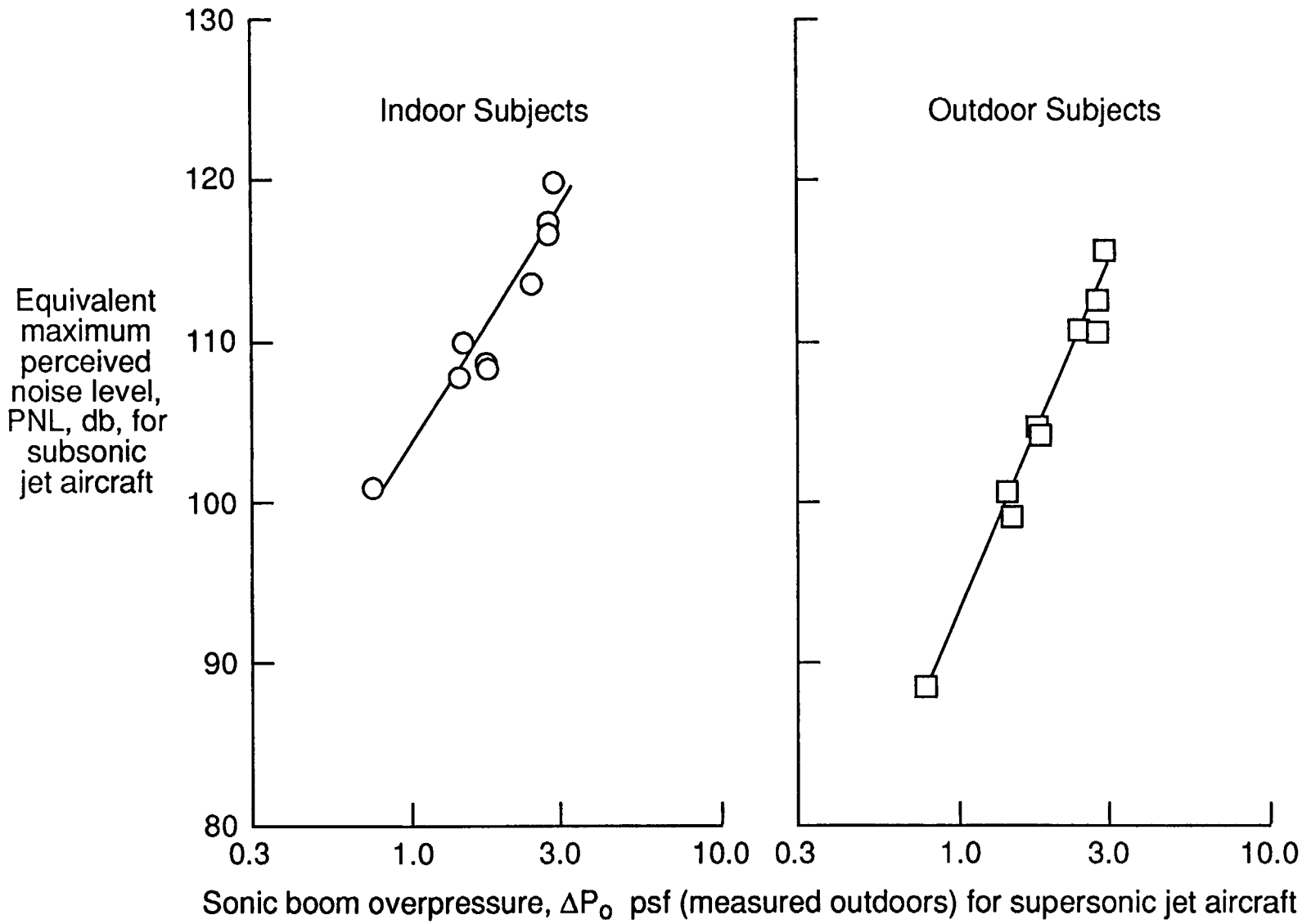

Figure 5. Equivalence of sonic booms and aircraft flyover noise as judged by indoor and outdoor subjects during Edwards AFB paired comparison listening tests (ref. 1 and 2).

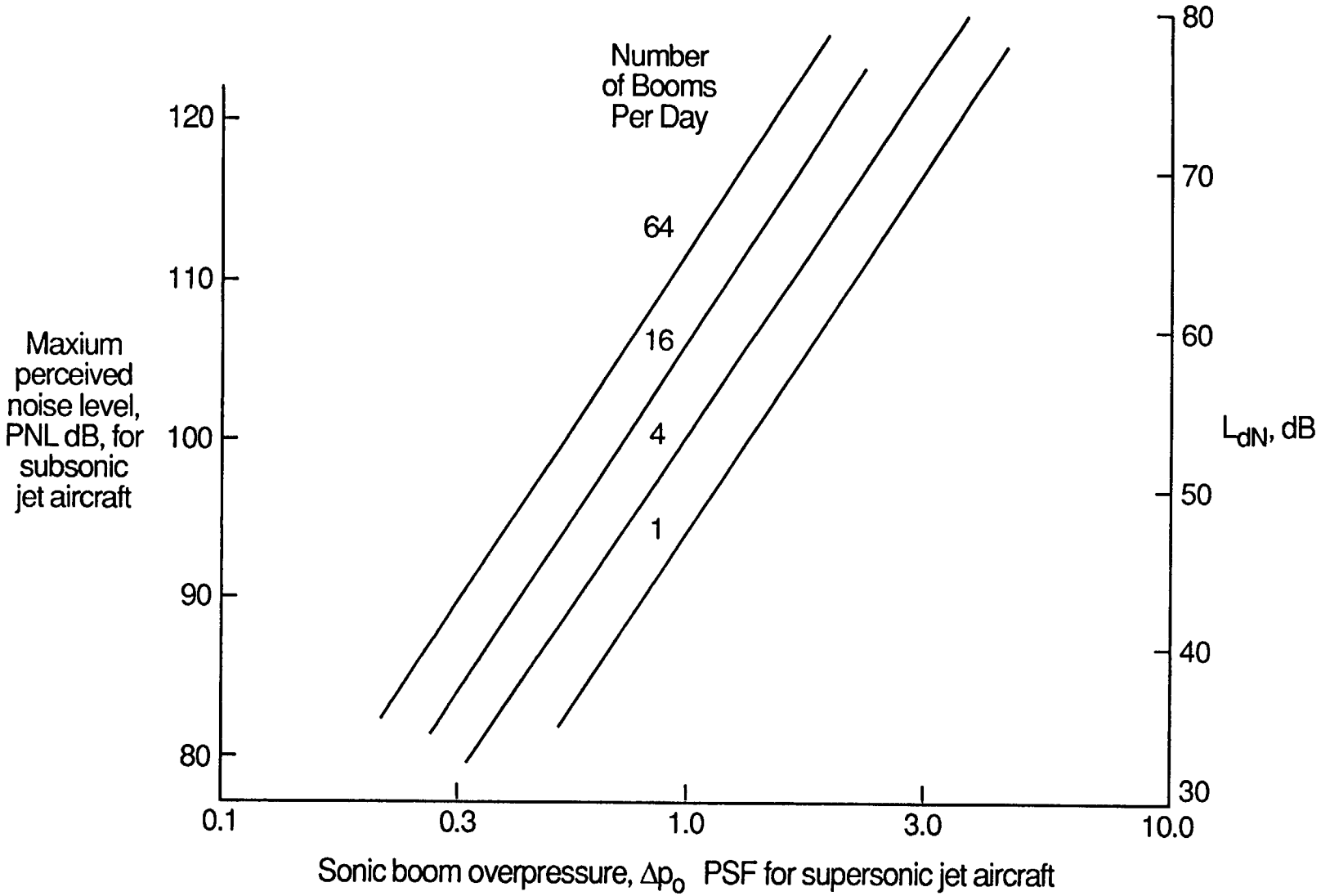

Figure 6. Equivalence of sonic booms and aircraft flyover noise as judged by outdoor subjects during Edwards AFB paired comparison listening tests.

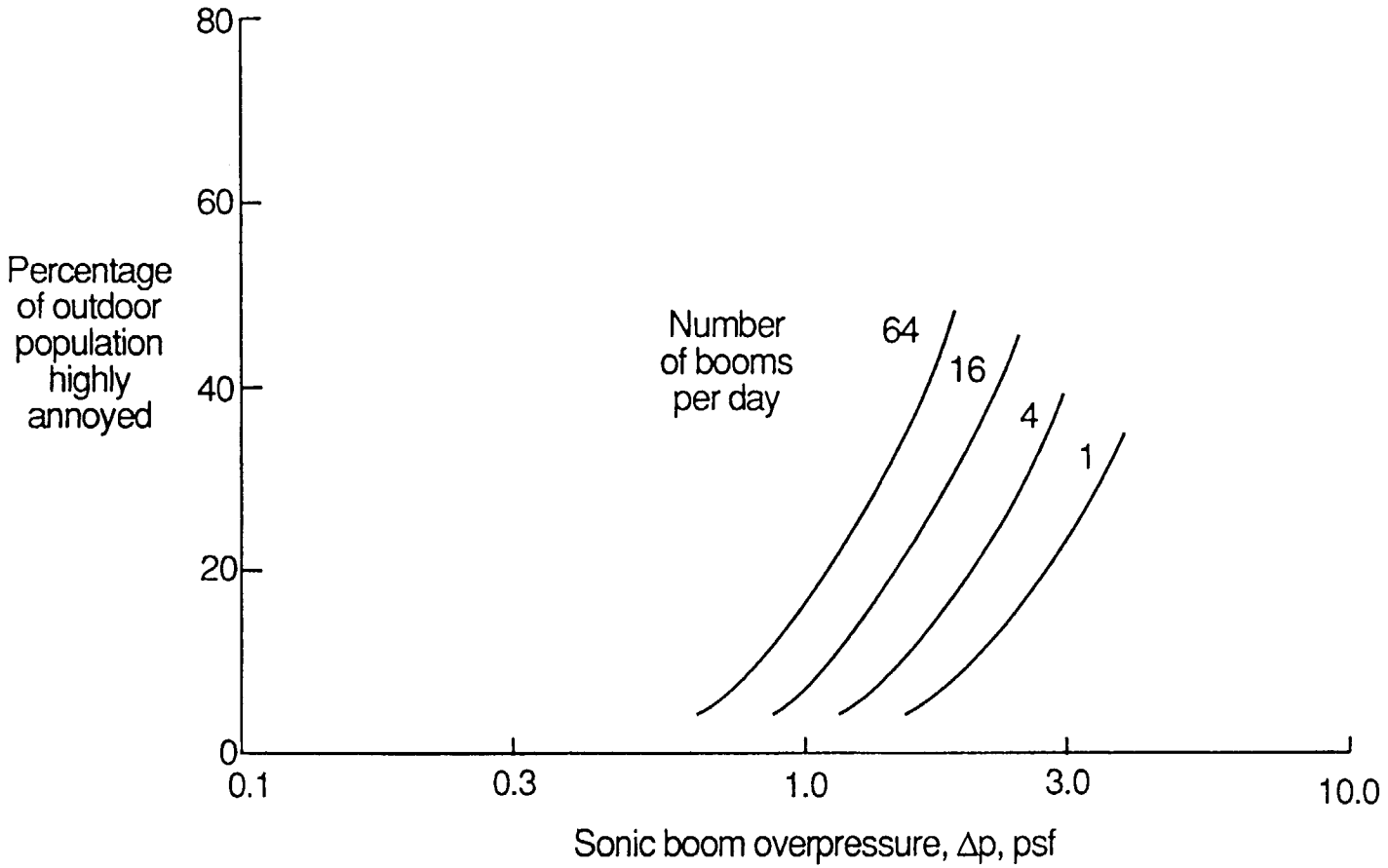

Figure 7. Percentage of outdoor population highly annoyed as a function of sonic boom overpressure for various numbers of booms per day. Predictions are basd on Kryter-Schultz relationships.

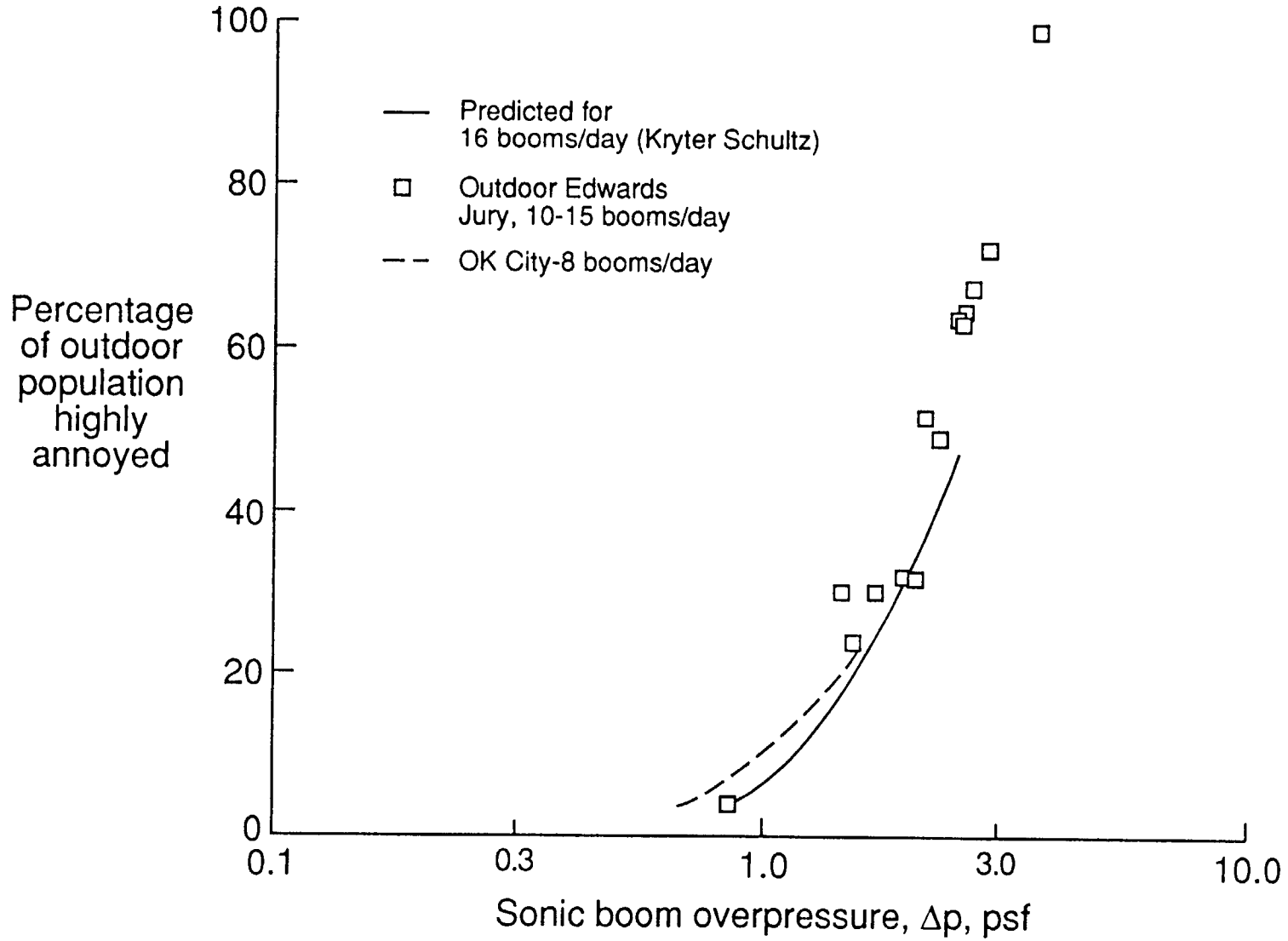

Figure 8. Kryter-Schultz predictions of percentage of outdoor population highly annoyed, compared with results of field studies.

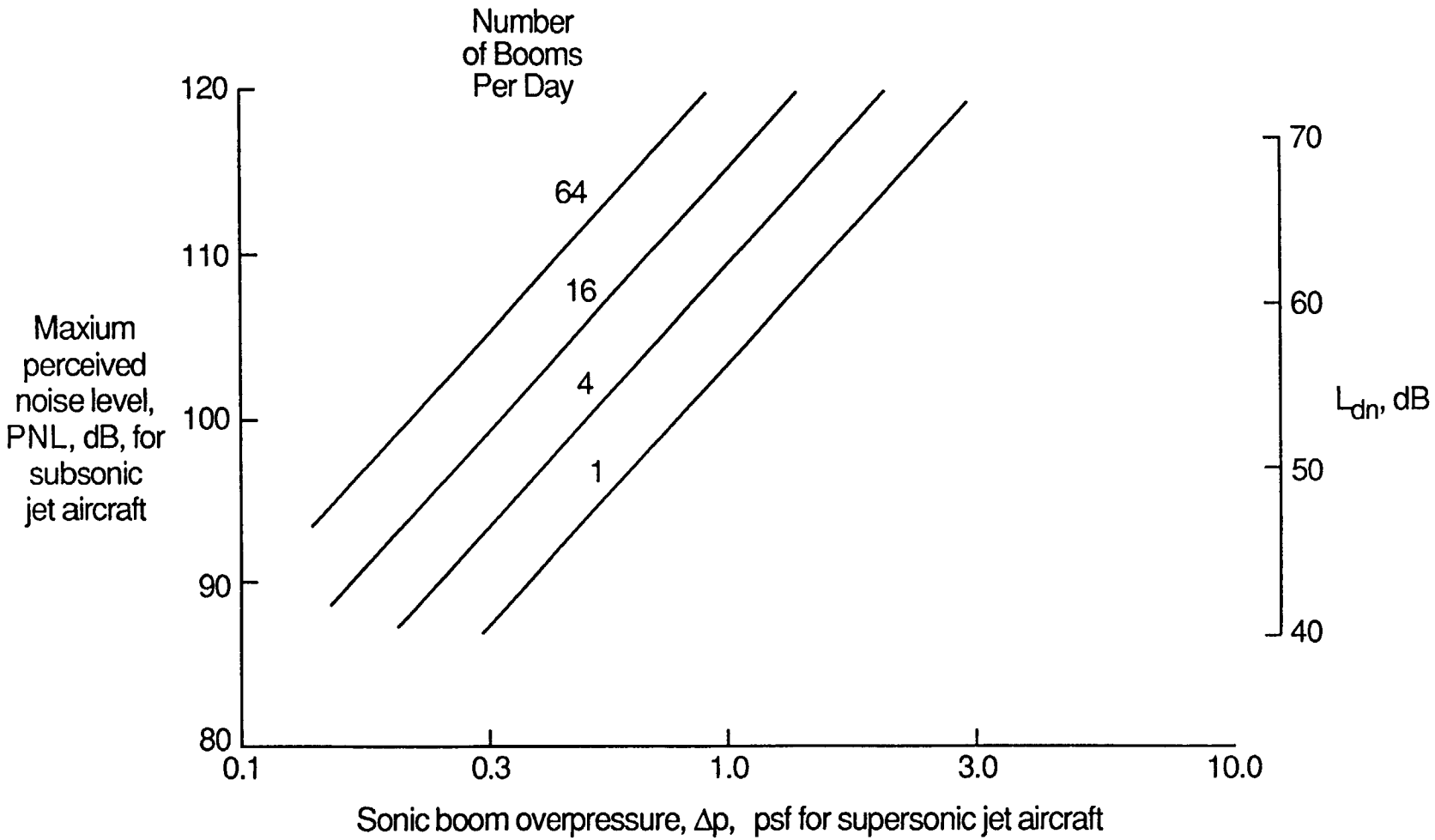

Figure 9. Equivalence of sonic booms and aircraft flyover noise as judged by indoor subjects during Edwards AFB paired comparison listening tests.

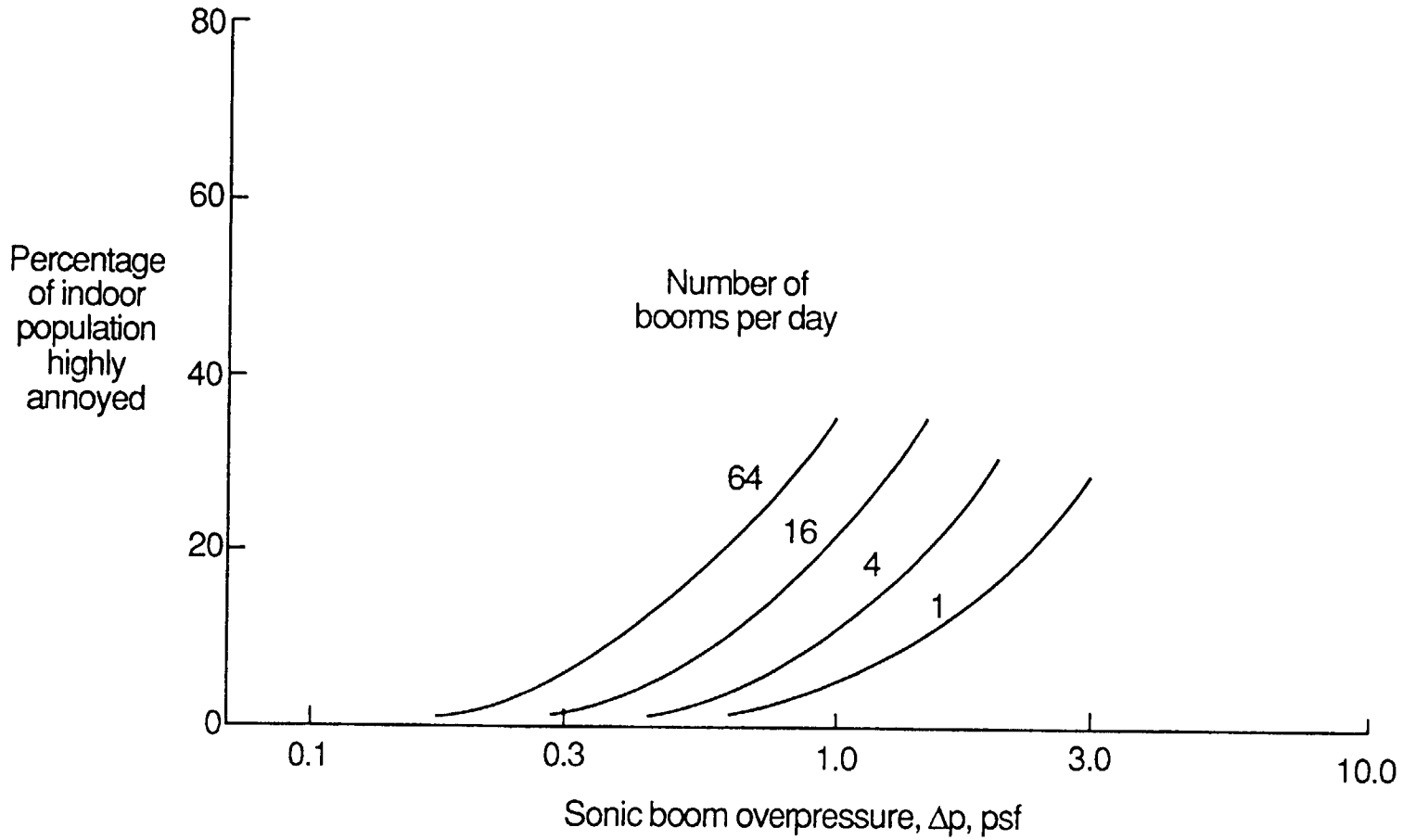

Figure 10. Percentage of indoor population highly annoyed as a function of sonic boom overpressure for various numbers of booms per day. Predictions are based on Kryter-Schultz relationships.

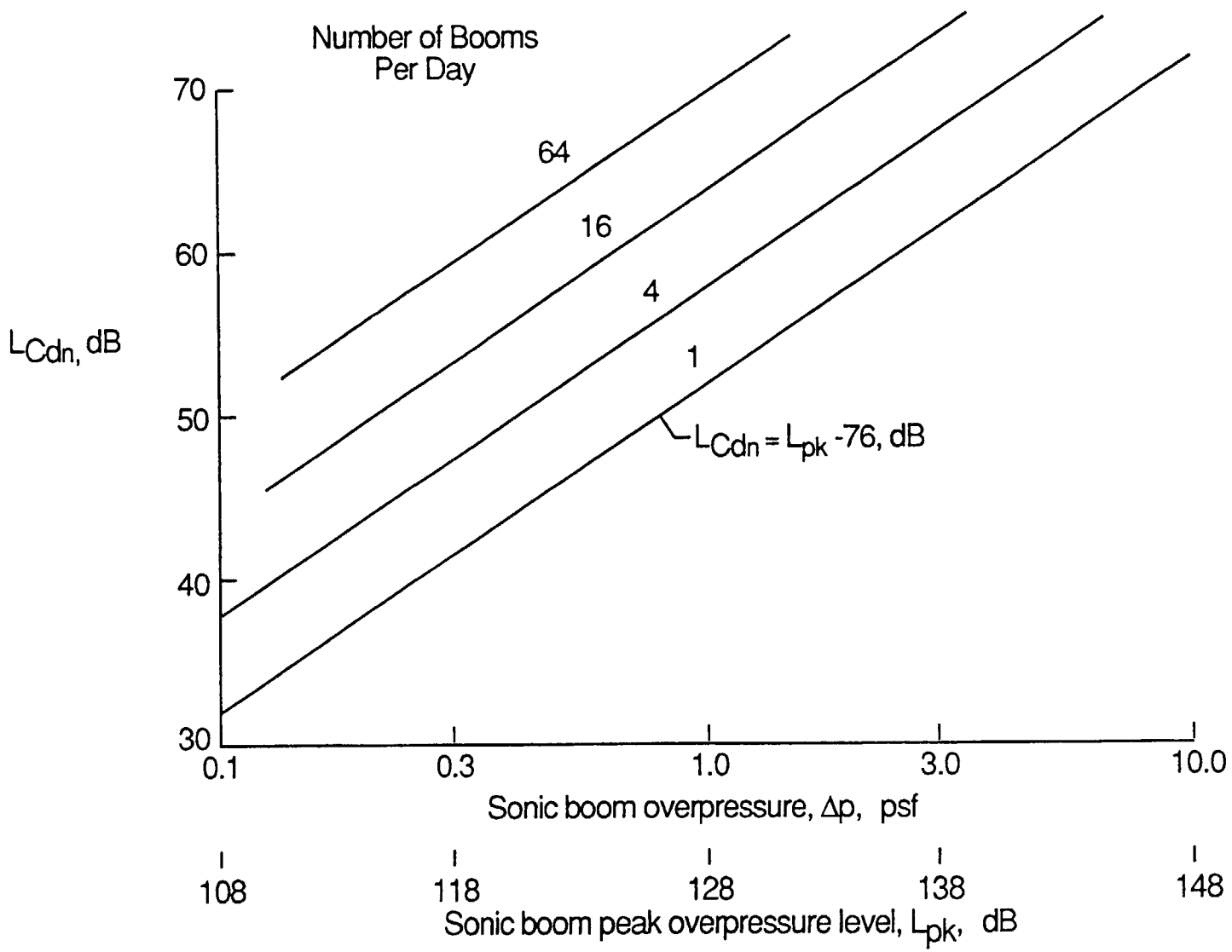

Figure 11. Equivalence of sonic boom peak overpressure level and the day-night average "C"-weighted sound level.

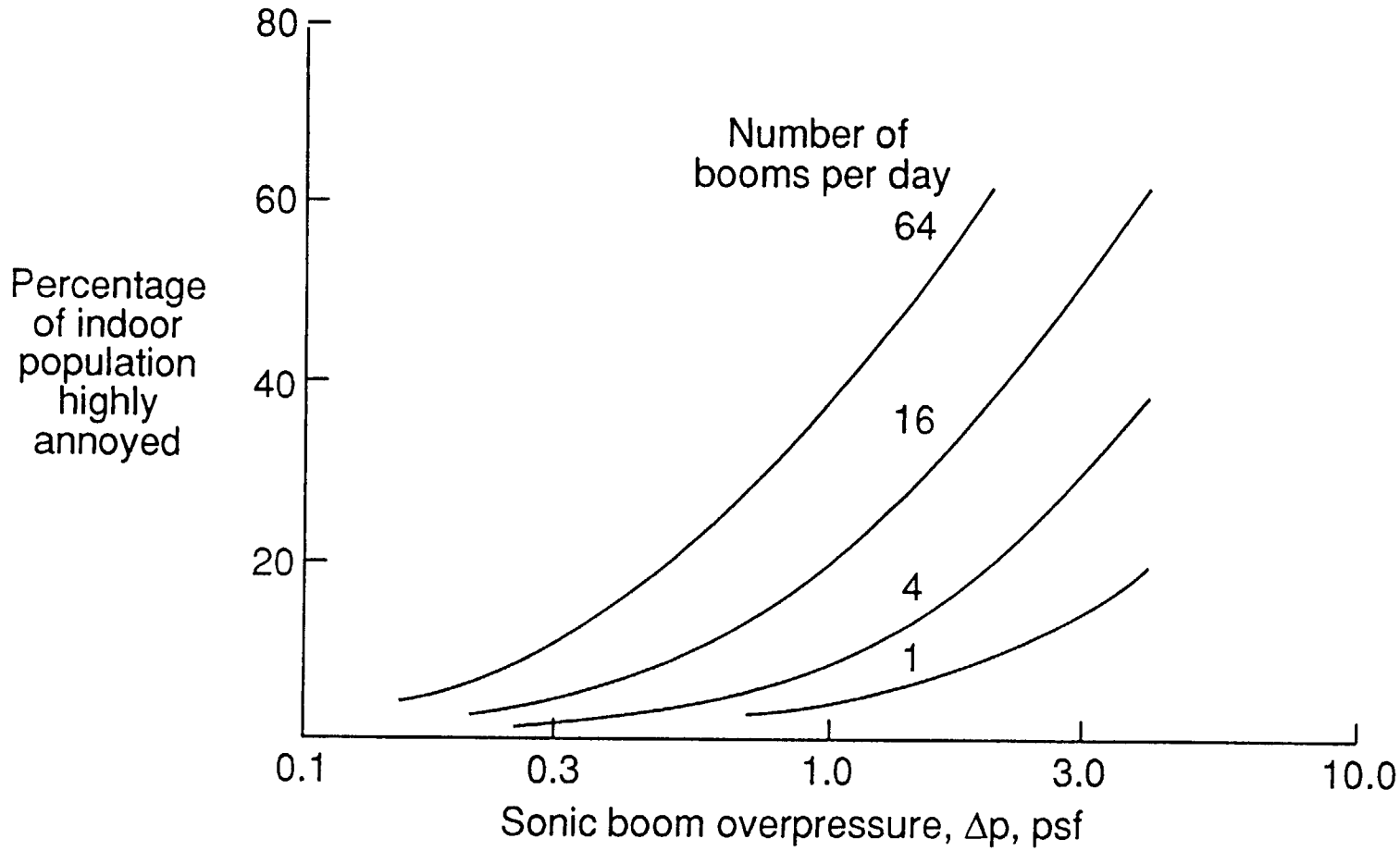

Figure 12. Percentage of indoor population highly annoyed as a function of sonic boom overpressure for various numbers of booms per day. Predictions are based on ANSI relationships.

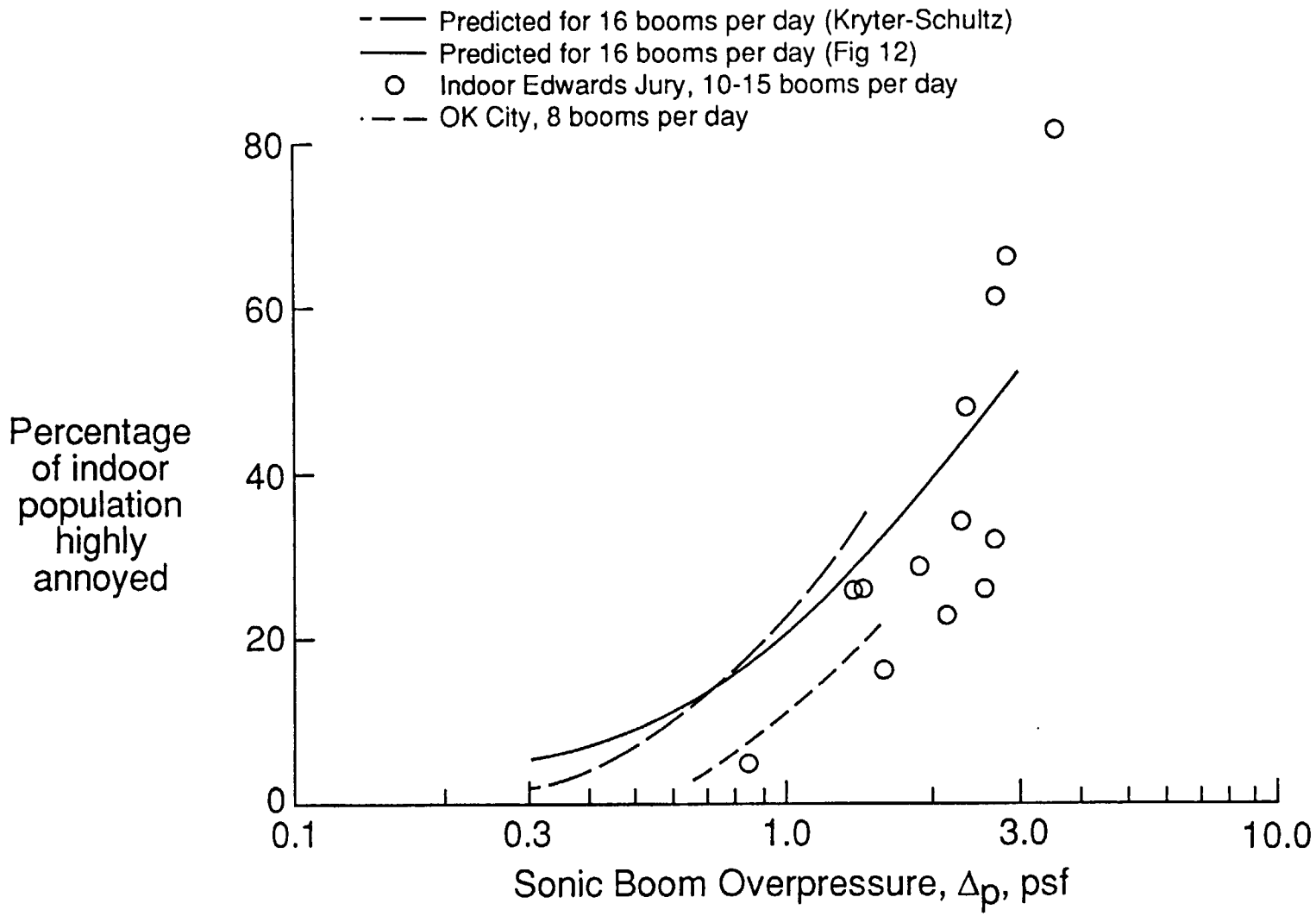

Figure 13. Kryter-Schultz prediction of percentage of indoor population highly annoyed, compared with results of field studies.

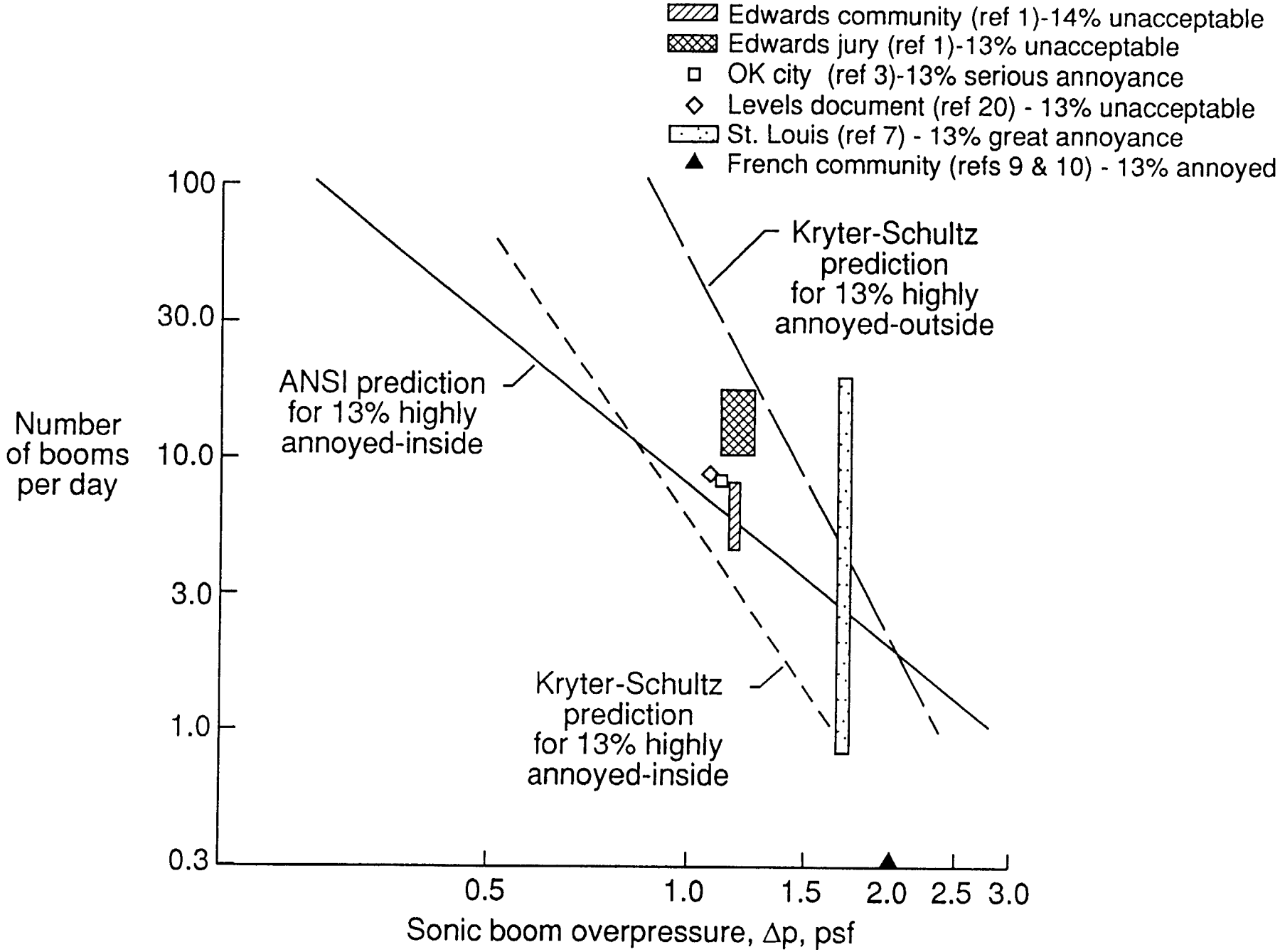

Figure 14. Comparisons of predicted and observed community exposures to sonic booms for a 13 percent highly annoyed community response.

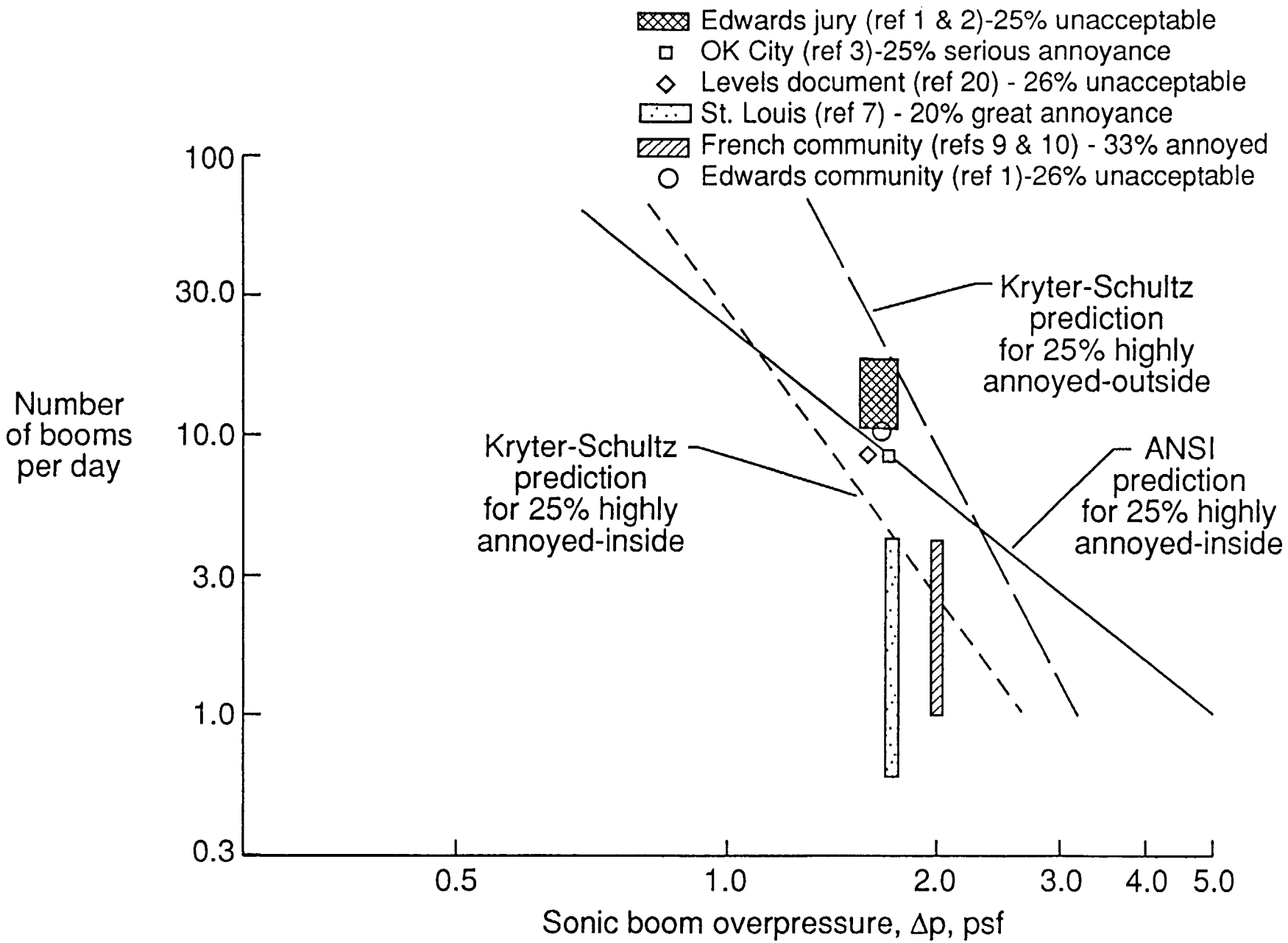

Figure 15. Comparisons of predicted and observed community exposures to sonic booms for a 25 percent hightly annoyed community response

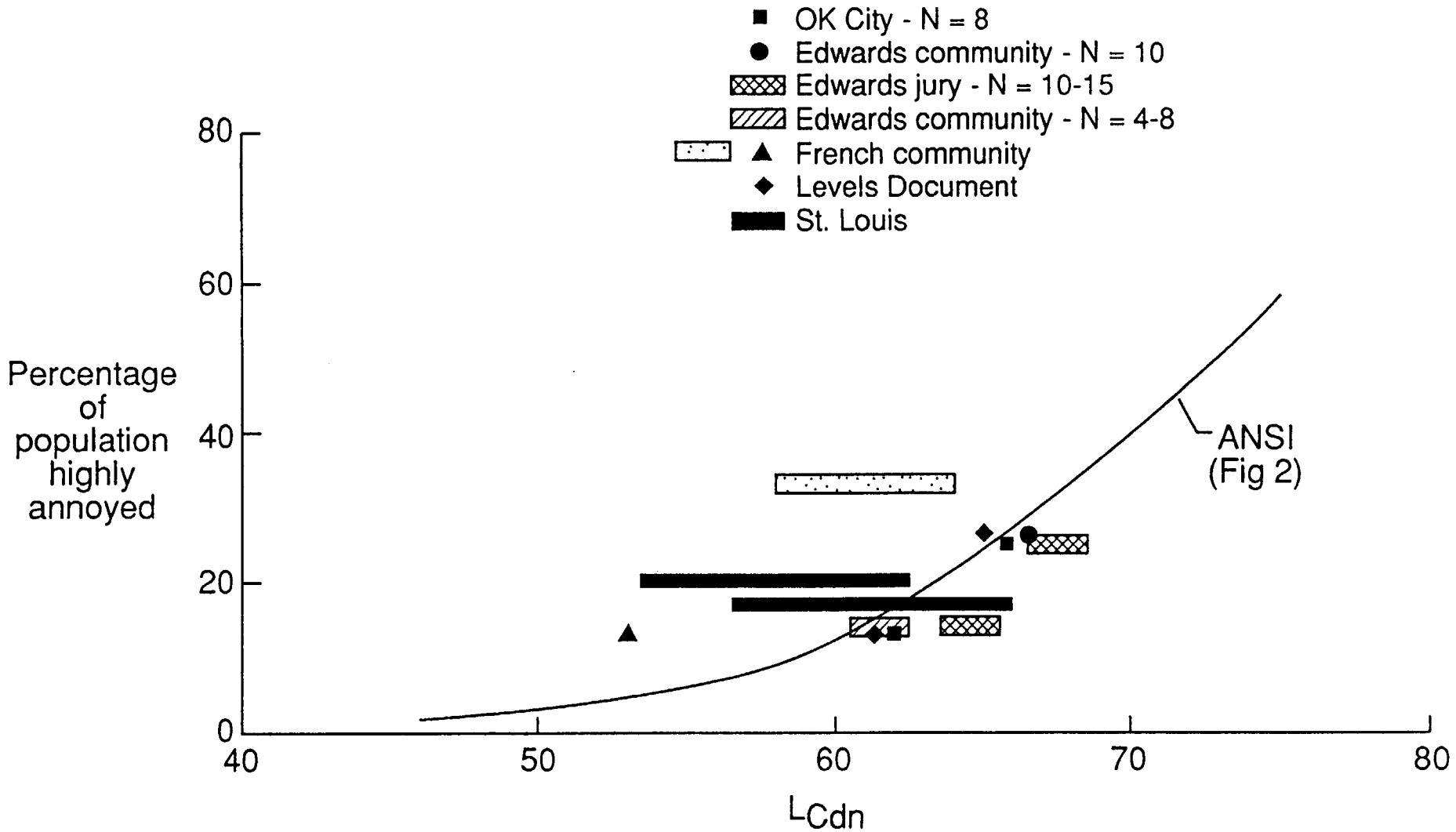

Figure 16. Predicted percentge of the population highly annoyed (ANSI) compared to various community observations.

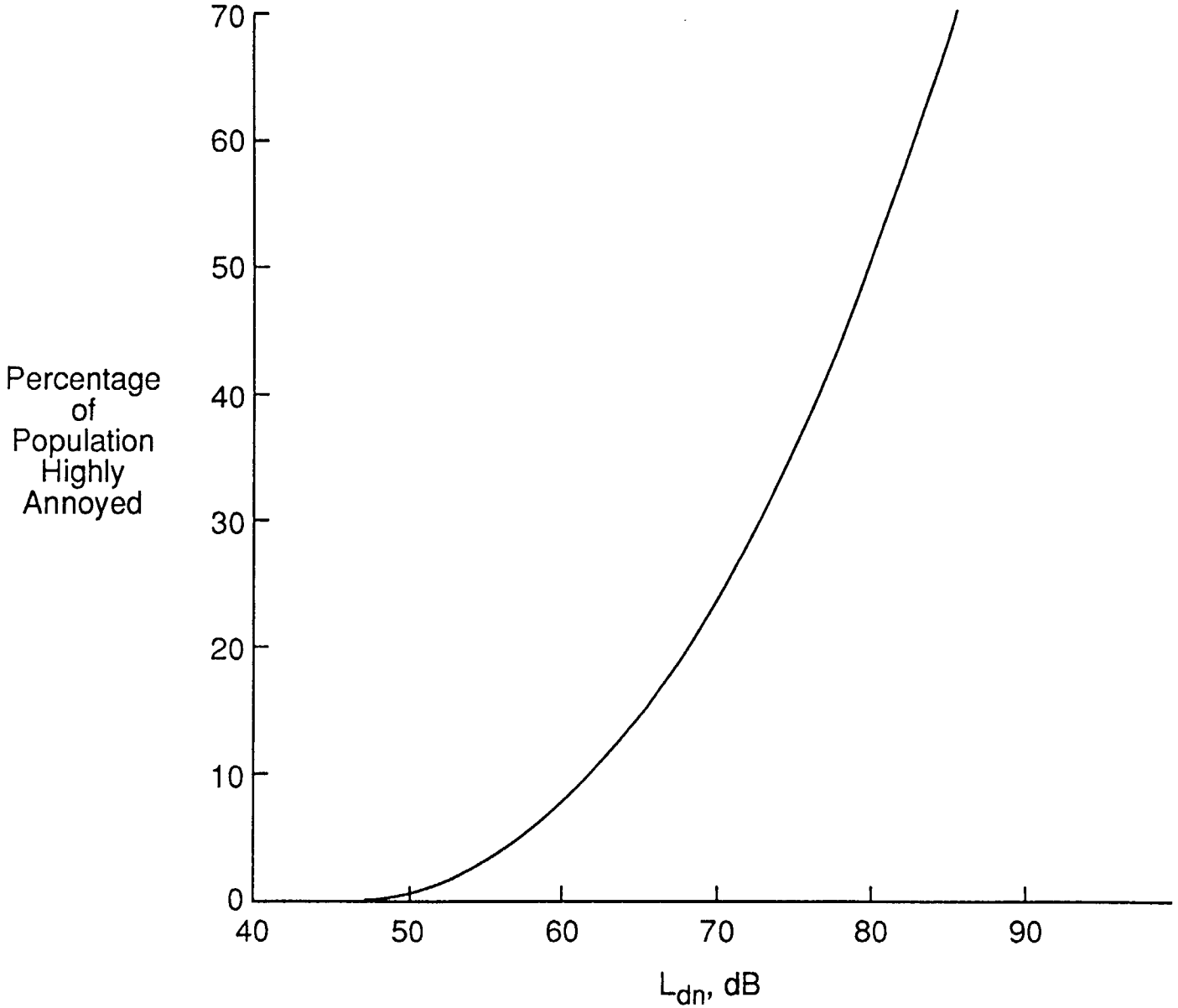

Figure 1. Percentage of population highly annoyed by subsonic transportation noise as a function of day-night average A-weighted sound level (ref. 11).

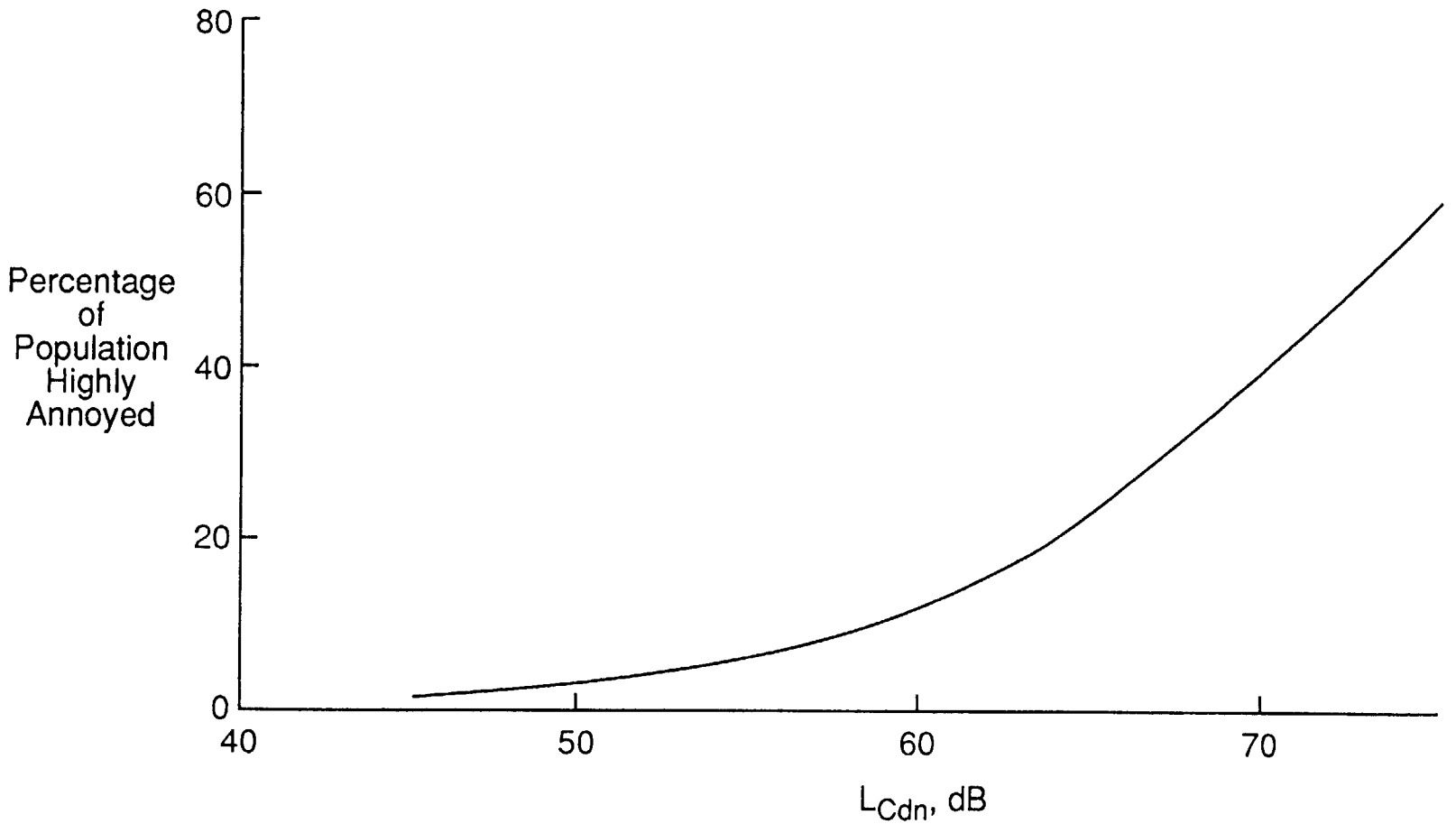

Figure 2. Percentage of population highly annoyed by high-energy impulsive sounds as a function of day-night average C-weighted sound level (ref. 14).

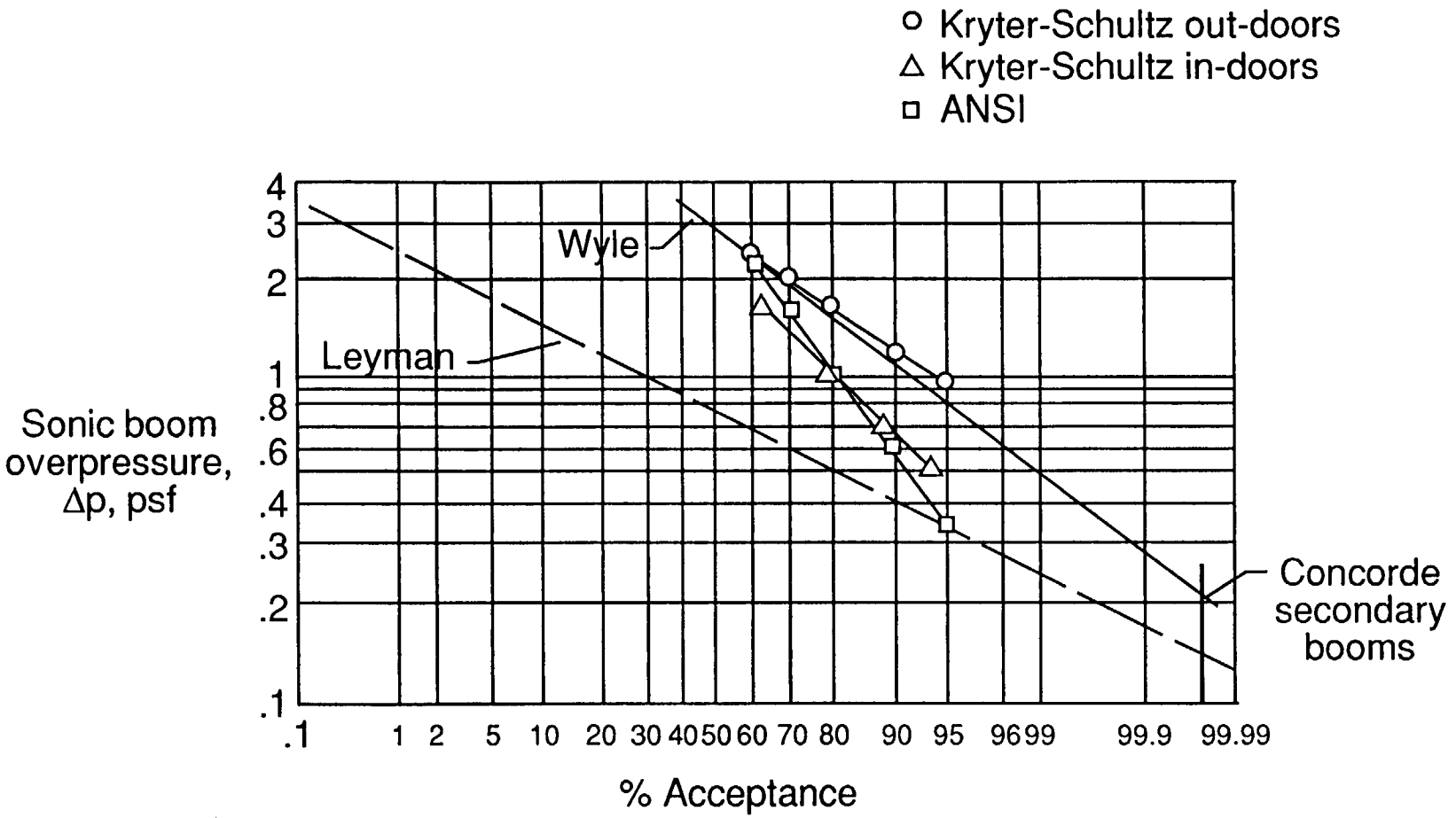

Figure 17. Predicted sonic boom acceptance.

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13. ABSTRACT (*Maximum 200 words*)
Two approaches to the prediction of community response to sonic boom exposure are examined and compared. The first approach is based on the wealth of data concerning community response to common transportation noises coupled with results of a sonic boom/aircraft noise comparison study. The second approach is based on limited field studies of community response to sonic booms. Substantial differences between indoor and outdoor listening conditions are observed. Reasonable agreement is observed between predicted community responses and available measured responses.

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